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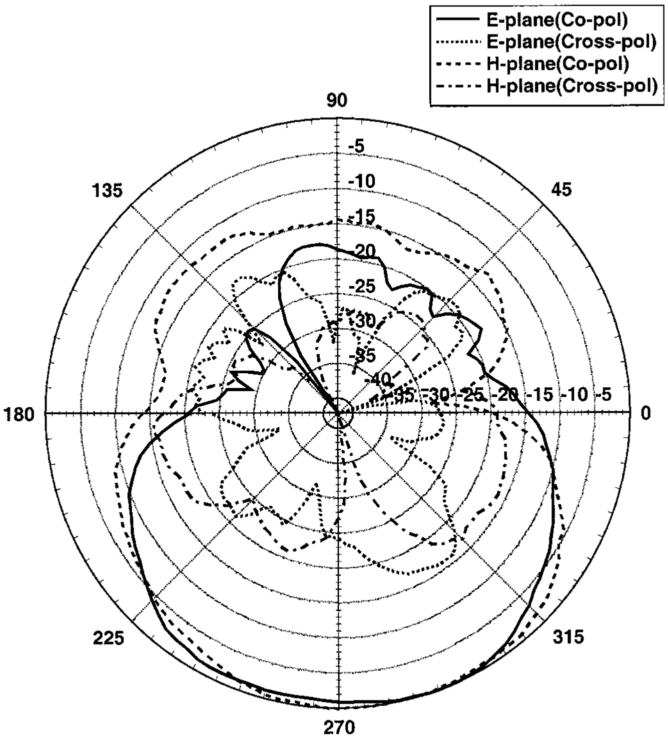

Fig. 4. Measured *E*- and *H*-planes co- and cross-polarization radiation patterns of the gain-enhanced antenna at 9.55 GHz. 270° is the endfire radiation direction in this measurement.

11%, which is much wider than the regular patch antenna realized on the similar substrate. The gain of the antenna varies from 5 dB to 7 dB over the operating bandwidth. In comparison with the broadband design, this design has four times narrower bandwidth but approximately 2 dB higher gain. By adding more directors, we expect that the gain can be further increased. To confirm the change in the absolute gain value, the radiation pattern is also plotted in Fig. 4. The beam-width of the radiation pattern is narrower than that of the broadband design while keeping a front-to-back ratio of 15 dB and a maximum cross-polarization level of -15 dB. The change in the radiation pattern is relatively small for the entire operating bandwidth [4].

VI. CONCLUSION

In this paper, a very compact and simple planar antenna based on the modification of the classic Yagi–Uda antenna has been presented. The antenna achieves extremely wide frequency bandwidth and good radiation characteristics in terms of beam pattern, front-to-back ratio, cross polarization and low mutual coupling. The antenna experimentally demonstrated a bandwidth of 48% for a $\mathrm{VSWR} < 2$, better than 12 dB front-to-back ratio, a gain between 3–5 dB, and a nominal radiation efficiency of 93%. Additionally, mutual coupling between antennas in a horizontal and vertical configuration were measured to be better than -20 dB in the entire operating band. Finally, a higher gain version of the quasi-Yagi antenna has been presented. In this case, measured gain varies between 5–7 dB across the operating bandwidth, where the increased gain has been achieved at the cost of reduced bandwidth. Adding additional directors has the potential of increasing the gain ever further.

The excellent radiation properties of this antenna make it ideal as either a stand-alone antenna with a broad pattern or as an array element. We believe that this antenna should find wide applications in wireless communication systems, power combining and phased arrays, as well as millimeter-wave imaging arrays. The broad pattern, low-mutual coupling and wide instantaneous bandwidth allow this antenna to be incorporated into multi-frequency phased arrays with very large scanning capability.

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Miniature Microstrip Antenna With a Partially Filled High-Permittivity Substrate

Byungje Lee and Frances J. Harackiewicz

***Abstract*—A new technique to reduce the overall dimension of a microstrip antenna using a partially filled high-permittivity substrate is proposed. The miniaturized microstrip antenna for a repeater system in a mobile communication cellular band (824–894 MHz) is designed with the proposed technique and manufactured with light weight and small size. Comparison between simulations, based on HP HFSS software and measurements are provided.**

***Index Terms*—Patch antenna, repeater system.**

I. INTRODUCTION

Microstrip patches are currently being used for many applications. However, the size of a conventional microstrip patch antenna is still

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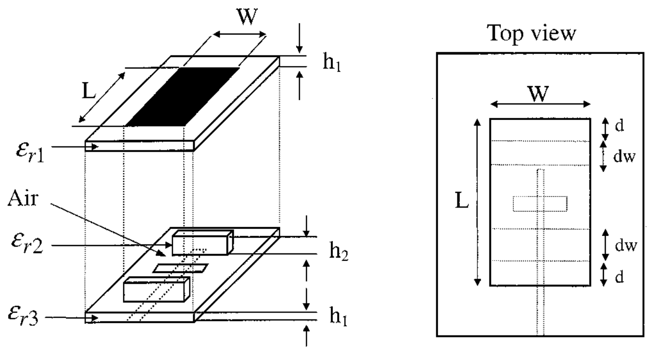

Fig. 1. The microstrip antenna with a locally inserted dielectric substrate.

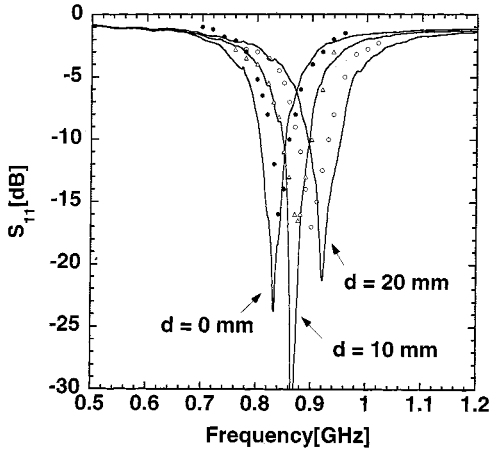

Fig. 2. The resonant frequencies for the different positions of the RDB. $L = 152$ mm, $W = 130$ mm, $h_1 = h_2 = 1.6$ mm, $h_2 = 18$ mm, $\varepsilon_{r1} = \varepsilon_{r2} = \varepsilon_{r3} = 4.7$, and $dw = 10$ mm [solid lines (measured); •, ▲, and ○ (calculated)].

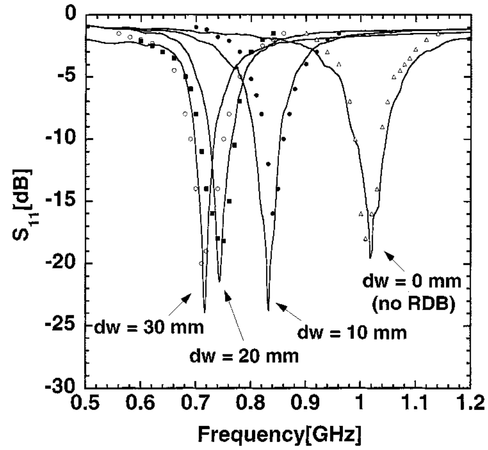

Fig. 3. The resonant frequencies for the different widths (dw) of the RDB. $L = 152$ mm, $W = 130$ mm, $h_1 = h_2 = 1.6$ mm, $h_2 = 18$ mm, $\varepsilon_{r1} = \varepsilon_{r2} = \varepsilon_{r3} = 4.7$, and $d = 0$ mm [solid lines (measured); ○, ■, •, and ▲ (calculated)].

somewhat large for the frequencies of less than 2 GHz. Although, microstrip antennas have being used for the indoor and outdoor repeater system of a mobile communication system at a Korean cellular band (824–894 MHz) and at a Korean Personal Communication Service (KPCS) band (1.85–1.99 GHz), the size of microstrip antennas are somewhat large compared with the dimension of a repeater system, which is 6.121 × 4.08 × 1.63 in (50 × 100 × 40 mm) at the cellular band in our case. The demand for new mobile communication devices and systems will certainly continue for several years, increasing the market pressure for efficient small antennas. These radiating devices should be optimized for each application, in order to get the best compromise between antenna volume, gain, and bandwidth. Therefore, several techniques have been proposed to effectively reduce the size of the microstrip patch antenna. High dielectric constant substrate materials have been proposed for small-size patch antennas [1]; however, only poor efficiency due to surface-wave excitation and narrow bandwidth have been presented. Shorting posts were used in different arrangements to reduce the overall size of the printed antenna [2], [3]. In addition, cutting slots in the radiating patch, a compact microstrip antenna has been implemented [4], [5]. Indeed, it remains quite difficult to miniaturize such radiating elements because this effort generally conflicts with electrical limitations or cost considerations. In this paper, we propose an alternative solution, based upon an optimal geometrical configuration with a partially filled high permittivity substrate.

II. DESIGN AND RESULT

The performances of microstrip antennas are related to the electric field distributions at each of the extremities of the printed radiating element. The microstrip antenna with a locally inserted dielectric substrate is proposed, as shown in Fig. 1. The resonant frequency of a microstrip antenna mainly depends on the length (L) of the patch, the thickness ($2h_1 + h_2$) of the substrate, and the permittivity of the substrate. The rectangular dielectric bar ($W \times dw \times h_2$) is placed under the radiating patch with varying distance d from the edge of the resonating patch. The calculated and measured resonant frequencies of the microstrip antenna for the different positions ($d = 0$, 10, and 20 mm) of the rectangular dielectric bar (RDB) are shown in Fig. 2. It is noticed that the size of a radiating patch can be effectively minimized when a RDB is placed under the edge of the patch ($d = 0$ mm). Now, the width (dw) of the RDB is increased by filling the dielectric material from the edge of the patch ($d = 0$ mm). The calculated and measured resonant frequencies of the microstrip antenna for the different widths (dw) of the RDB are shown in Fig. 3. One can see that by inserting a RDB, which has a small width compared with patch length (L), the antenna size can be significantly reduced. It is apparent that for the case of a conventional microstrip antenna, the smallest patch length can be obtained by completely filling between the ground plane and antenna substrate with a high-permittivity substrate. However, the bandwidth (VSWR < 1.5) of 70 MHz and a gain of 6 dB, which are requirements of an antenna for Korean repeater systems in a mobile communication cellular band, could not be achieved because increasing the dielectric constant results in decreasing the gain and bandwidth. For antennas in the current marketplace, simply adding an air layer into the whole volume between the ground plane and antenna substrate has eliminated these kinds of limitations. However, this air layer brings an even larger dimension of antenna than that of a repeater system. Concerned about the ever reduced size of antennas required for industrial applications, in this paper, a small-size and light-weight antenna is proposed by using an optimal geometrical configuration with a partially filled high-permittivity substrate. It should be noted that the manufacturing cost will be increased for both antennas of a partially filled (proposed method) and completely filled (conventional method) with a high-permittivity substrate. The reason is that traditional microstrip etching techniques may not applied for mass production of these types of antennas due to the high-substrate thickness($h = 2h_1 + h_2 = 21.2$ mm). However, the air gap in the proposed antenna will reduce the weight and material cost. Fig. 4 shows a patch antenna (left) with the proposed method and

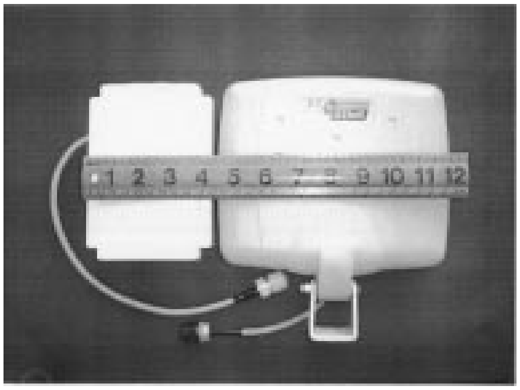

Fig. 4. The overall view of manufactured microstrip antennas.

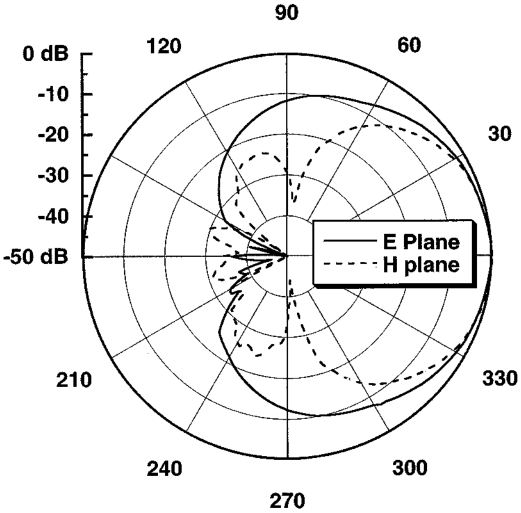

Fig. 5. The radiation pattern of the patch antenna at 836.5 MHz.

a conventional antenna (right) with an air layer filling the whole volume under the patch. The overall dimensions in inches for the proposed and conventional antennas are $6.00 \times 4.20 \times 1.26$ in ($148 \times 103 \times 31$ mm) and $7.35 \times 7.14 \times 1.90$ in ($180 \times 175 \times 47$ mm), respectively. Over 50% antenna dimension reduction is achieved with the proposed method. The weights of the proposed and conventional antennas are 0.78 and 1.38 lb, respectively. The measured gain of the proposed antenna is over 6 dB in the full cellular band. The measured impedance bandwidth (VSWR < 1.5) for the proposed antenna is 92 MHz. The measured radiation pattern is also shown in Fig. 5. The half-power beamwidths for the horizontal and vertical patterns are $78^\circ \pm 3^\circ$ and $58^\circ \pm 3^\circ$, respectively. A reflector was used to reduce the back radiation of the slot-coupled microstrip antenna.

III. CONCLUSION

A novel design of a miniaturized microstrip antenna has been studied. It is shown that placing the RDB under the edge of the resonating patch can reduce the dimension of microstrip antenna. A fair agreement between measurement and simulation of resonant frequency and bandwidth has been shown. The proposed method with shorting posts and slots may obtain more reduction of the overall size of the printed antenna, but with increased cost. In the future, this technique will be extended to an optimal geometrical combination of a low permittivity substrate with a high-permittivity substrate for possible size reduction and increased bandwidth.

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Radiation Patterns and Correlation of Closely Spaced Linear Antennas

Kevin Boyle

***Abstract*—A simple point source analysis is used to prove that in theory, completely decorrelated reception can be achieved from two linear antennas with an arbitrarily small spacing. The conditions necessary to achieve this are consistent with two high gain (superdirective) beams in opposite directions. It is shown that the horizontal radiation patterns and correlation coefficient of arrays of vertically orientated linear antennas can be found via an exact relation to simple, point-source theory that includes the effects of mutual coupling. This theory leads to practically achievable optimum diversity designs at closer spacings than previously thought possible. The theory is illustrated for a dual antenna configuration and can be extended to multiple antennas.**

***Index Terms*—Antenna radiation patterns, correlation, diversity, linear antennas.**

I. INTRODUCTION

Antenna diversity is a well-known technique for mitigating the effects of multipath propagation. Conventionally, spatial diversity has been employed based on Clarke's well-known formula for the spatial envelope auto-correlation coefficient, ρ_e given by [1]

$$\rho_e = |\rho|^2 = J_0^2(kx) \tag{1}$$

where ρ is the auto-correlation coefficient, k is the wavenumber, x is the distance, and J_0 is a zeroth-order bessel function of the first kind. Angular (radiation pattern) diversity has received less attention. However, it offers the potential advantages of close antenna spacing, equal average received branch powers, and reduced delay spread. This communication shows how angular diversity can be achieved using closely spaced linear, vertically polarized antennas, based on a simple point source analysis.

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